DOCUMENT RESUME

ED 211 425 SO 013 804

AUTHOR Kohler, Fred
TITLE Classroom Exercises Concerning the Effect of Weather Conditions on Air Quality in Illinois.
PUB DATE 29 Oct 81
NOTE 41p.: Paper presented at the Annual Meeting of the National Council for Geographic Education (Pittsburgh, PA, October 29, 1981).

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Air Pollution; Climate; Data Analysis; Environmental Influences; *Geography Instruction; Graphs; Higher Education; Learning Activities; *Meteorology; Tables (Data); Teaching Methods; *Weather
IDENTIFIERS Carbon Monoxide; *Climatology; Nitrogen Dioxide; Ozone; Sulfur Dioxide

ABSTRACT

This paper contains sample exercises that investigate weather and air quality relationships for use in college-level introductory courses in climatology and meteorology. The exercises will provide students with an opportunity to apply meteorological principles to a specific geographic location, in an effort to better understand the significant role that weather plays in enhancing or reducing air pollution levels. The first part of the paper discusses the general characteristics of the five air pollutants to be studied in the exercises--ozone, sulfur dioxide, total suspended particles, carbon monoxide, and nitrogen dioxide. The second half of the paper contains tables and graphs describing ozone pollution and weather conditions in Chicago and a detailed discussion of specific methods that students can use to analyze these tables and graphs. This detailed discussion is intended to provide by example procedures that students can utilize in their investigation of the other four air pollutants. (Author/RM)

CLASSROOM EXERCISES CONCERNING THE EFFECT OF WEATHER CONDITIONS ON AIR QUALITY IN ILLINOIS

A paper presented at the 1981 meeting of the

NATIONAL COUNCIL FOR GEOGRAPHIC EDUCATION

October 29, 1981

by

Fred Kohler

Department of Geography

Western Illinois University

CLASSROOM EXERCISES CONCERNING THE EFFECT OF WEATHER CONDITIONS ON AIR QUALITY IN ILLINOIS

Introduction

Most introductory courses in climatology and meteorology devote time to discussing the manner in which atmospheric conditions can affect air quality. A satisfactory understanding of such conditions requires an examination of such meteorological phenomena as lapse rates, stability and instability, temperature inversions, as well as special factors like local topography and regional weather patterns. Occasional me permits a general examination of the characteristics, sources and hea ffects of such air pollutants as ozone, total suspended particulates and sulfur dioxide. Frequently, however, a lack of data does not permit case studies which could examine in detail the weather conditions that are most often associated with high concentrations of major air pollutants. Classroom exercises which examine this relationship would provide students with an opportunity to apply meteorological principles to a specific geographic location, in an effort to better understand the significant role that weather plays in enhancing or reducing air pollution levels.

From 1976 to 1978 the state of Illinois experienced an unusually large number of air pollution episodes, especially in the larger metropolitan areas. A major problem during the warmer part of the year was ozone. The concentration of ozone and its longevity are largely determined by weather conditions. According to the Illinois Environmental Protection Agency[1], "The role of weather in the production of ozone cannot be overemphasized."

In addition to ozone (O_3), data on total suspended particulates (T S P), sulfur dioxide (SO_2), carbon monoxide (CO) and nitrogen dioxide (NO_2) were collected and examined for periods when concentrations were especially high during 1978 in the city of Chicago. Average daily air pollution data were obtained on microfiche from the Illinois Environmental Protection Agency, Division of Air Pollution Control for monitoring sites in northeastern Illinois.[2] Average daily weather data for 1978 were purchased from the National Weather Service for Midway Airport. The considerable amount of air pollution information required that this preliminary examination be restricted to monitoring sites nearest to Midway Airport (Figure 1). It was assumed that the weather records at Midway Airport were representative of the weather conditions experienced at monitoring sites located nearby.

Air Quality

A discussion of the general characteristics of the five air pollutants provides a background that should be useful in clarifying questions posed later in some of the specific exercises. Figure 2 indicates the trends in air pollution emissions from 1970 through 1978. If ozone emissions were added to the values in Figure 2, the six categories combined would account for 98% by mass of all air pollution generated in this country.

Total suspended particulates have undergone the most dramatic decrease in emissions during the nine year period. This air pollution problem is not as serious a health hazard as the other pollutants which have not been reduced as rapidly. Modest gains in reducing sulfur dioxide emissions have been achieved during the 1970's. Notice, however, that since 1976 only slight reductions in sulfur dioxide emissions have occurred. The percentage change

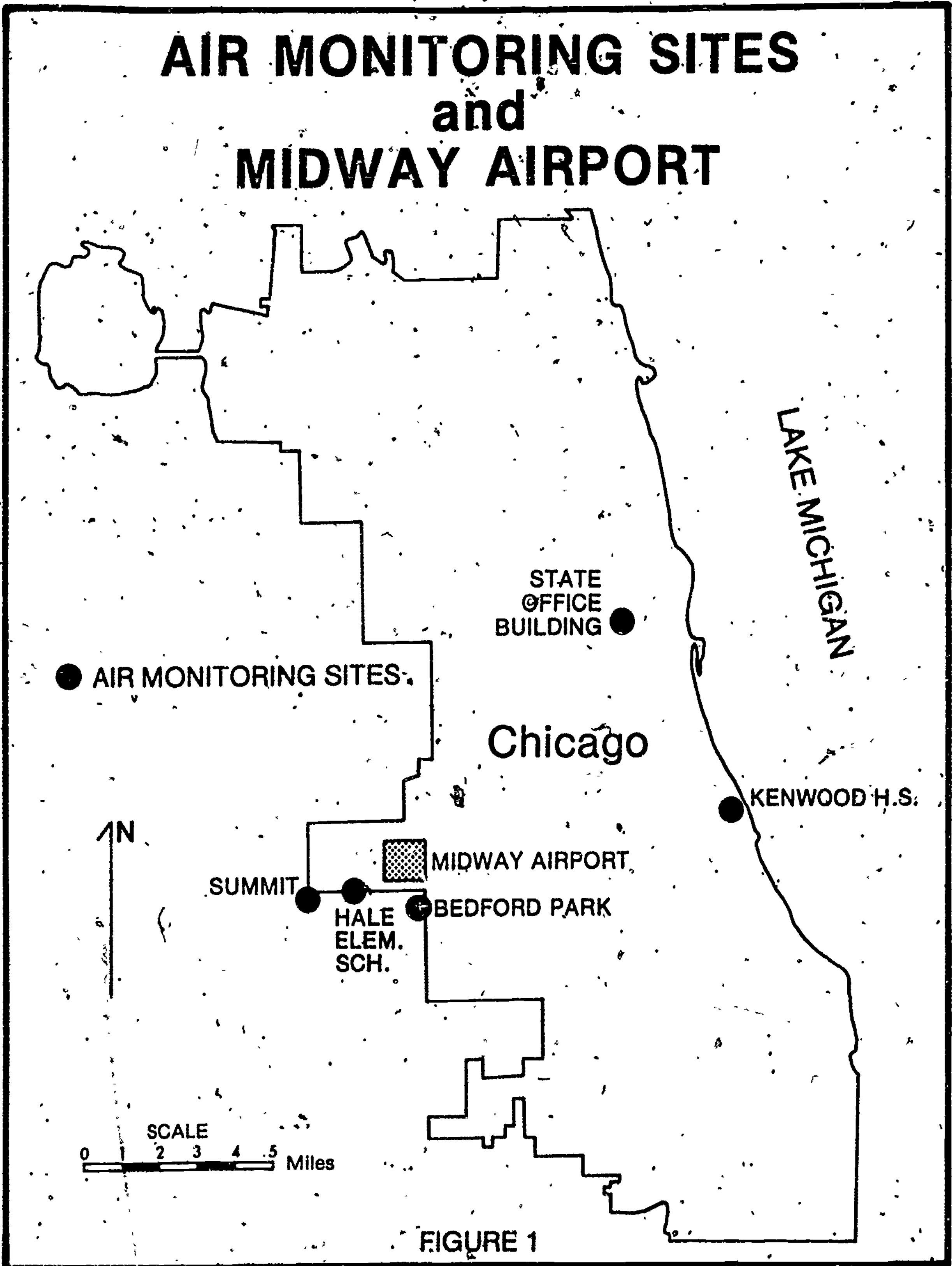

AIR MONITORING SITES
and
MIDWAY AIRPORT
LAKE MICHIGAN
STATE
OFFICE
BUILDING
AIR MONITORING SITES
Chicago
KENWOOD H.S.
N
MIDWAY AIRPORT
SUMMIT
HALE
ELEM.
SCH.
BEDFORD PARK
SCALE
0 1 2 3 4 5 Miles

FIGURE 1

FIGURE 2

NATIONAL AIR POLLUTION EMISSION ESTIMATES, 1970-1978

(million metric tons per year)

Year	TSP	SO_2	NO_2	HC	CO
1970	23.2	29.8	19.9	28.3	102.6
1971	22.0	28.2	20.6	27.8	103.1
1972	21.0	29.3	21.6	28.3	104.4
1973	20.3	30.4	22.4	28.4	103.5
1974	17.9	28.5	21.8	27.1	99.6
1975	14.6	26.2	20.9	25.3	97.2
1976	14.1	27.4	22.5	27.0	102.9
1977	13.6	27.2	23.4	27.1	102.4
1978	12.5	27.0	23.3	27.8	102.1
Percentage change, 1970-78	-46.1	-9.4	+17.1	-1.8	-.5

Source: U.S. Environmental Protection Agency, National Air Pollutant Emission Estimates, 1970-1978 (Washington, D.C., 1980), p. 2.

in the amount of hydrocarbons and carbon monoxide generated between 1970 and 1978 remained nearly the same. In 1975 totals for both pollutants were lowest and have since increased slightly but not enough to exceed the highest values recorded in 1972 and 1973. Since hydrocarbons are the principal contributor to the formation of ozone they will be discussed later in greater detail in conjunction with that pollutant rather than examined separately. Data on ozone emissions were not available during the years represented by Figure 2. Recent trends, however, indicate that the level of ozone remained fairly constant nationwide because the principal contributor to its formation, hydrocarbons, has maintained nearly the same level of output in recent years. In 1978, carbon monoxide and ozone were the major air pollutants responsible for the unhealthy air being inhaled in America's urban centers. Nitrogen dioxide emissions have been the most difficult to reduce since 1970. Total emissions have slowly, but steadily increased making such a trend unique among air pollution emissions in the United States. A more detailed examination of each of the five air pollutants follows.

Ozone:

Ozone pollution occurs when hydrocarbons and nitrogen oxides are mixed in the presence of intense sunlight. Hydrocarbons are the principal contributor in the formation of ozone and are derived mainly from highway vehicles and industrial processes. Nitrogen oxides, primarily nitrogen dioxide, are produced almost entirely by highway vehicles and electric power plants. Sunlight is most intense during the summer which makes ozone pollution a predominately warm weather phenomenon.

This highly reactive, pungent, colorless gas belongs to a group of chemicals known as photochemical oxidants. Ozone is frequently used as the index for estimating total photochemical oxidants even though some researchers contend it is not the best index. It is recommended by health officials that no working environment should average more than 100 parts per billion (ppb) ozone during an eight hour work day. Chest discomfort can be experienced when ozone levels approach 300 ppb. Eyes frequently water when ozone levels reach 150 ppb. Ozone can cause irritation to the eyes and lungs with amounts as low as 100 ppb. Physical performance can be impaired when ozone levels reach 30 ppb. Unfortunately, ozone can react with other air pollutants, such as carbon monoxide to produce considerable irritation to the respiratory tract. Damage to some kinds of vegetation occur when ozone levels are 50 ppb or greater for more than four hours. Frequently leaves become st ippled or flecked when exposed to ozone. Damage to materials, such as rubber and fabrics does occur from excess ozone but is not well documented.

Ozone producing pollutants form over a period of several hours which permits prevailing winds to carry the mixture downwind for many miles. During this time the sun can "bake" the mixture of pollutants and generate very high ozone levels 30 to 50 miles away from the original source of emissions. Areas affected by ozone can vary in size from relatively small and barely detectable to major air masses capable of engulfing the entire state of Illinois. Ozone pollution is not restricted to the urban areas that produce them. Studies[3] indicate that rural areas 150 miles from St. Louis, Missouri, showed ozone levels that were almost identical to those of the city.

Ozone in Illinois is considered a violation of ambient air quality standards when levels exceed 80 ppb for a one hour average. This figure is for both the primary and secondary standards. A primary standard represents a level of air quality necessary to protect the public health. A secondary standard is a level of air quality required to protect the public welfare (vegetation, materials and property). The ozone season officially begins May 1 and ends September 30. Traditionally the highest levels are reached from mid-July to mid-August. In 1978, the highest ozone levels occurred in late August and extended into September. A record eight yellow ozone alerts were declared by the Illinois Environmental Protection Agency with the first occurring on August 22. Such an alert is issued when ozone levels exceed 170 ppb for a one hour average and weather conditions are expected to remain the same the next day. Ozone advisories were declared for a record total of 797 station-days in cities statewide in 1978. Advisory status is reached when ozone levels exceed 70 ppb for a two hour average and conditions are expected to continue the following day. The weather conditions that contribute to the elevated ozone levels during an advisory include temperatures between 80°F and 90°F, average wind speeds less than 5 miles per hour, stagnant air associated with high pressure, lack of rainfall and most important lots of sunshine. Ozone concentrations are intensified when the previous weather condition persists for two or more days in a row.

The first ozone advisory for Chicago was issued on May 10. Even though the ozone season officially ends on September 30, continued warm weather caused the Illinois Environmental Protection Agency to issue special ozone advisories during October and, for the first time since monitoring began in 1974, in November. The first yellow alert was issued in early September for the Chicago area.

During 1978 the city of Chicago experienced a total of 52 days when an ozone advisory was issued and one day when a yellow alert was declared.

Sulfur Dioxide:

Sulfur oxides are atmospheric pollutants that result primarily from the burning of fossil fuels containing sulfer compounds. The burning of coal generates about twice the quantity of sulfur oxides as oil and natural gas combined. Steam generated electric power plants operated by industry and electric utility companies account for a majority of emissions, with industrial processes such as refining of petroleum, manufacture of sulfuric acid and smelting of ores containing sulfur making up the rest. Sulfur dioxide is the best known of the sulfur oxides and is frequently used as the index for all such oxides. Controversy still exists concerning how well sulfur dioxide represents ambient sulfates as a whole. Some sulfur oxides are more toxic in the environment than sulfur dioxide, but account for much less of the total sulfate emissions by weight. Sulfur dioxide problems are generally located near areas where emissions are occurring, but can on occasion be subject to long range transport.

Once in the atmosphere some sulfur dioxide can be converted to sulfur trioxide (SO_3) and even to a sulfuric acid mist if water vapor is present. Sulfuric acid droplets and other sulfates may account for 5 percent to 20 percent of the total suspended particulate matter in urban air. Many health problems can occur as a result of breathing air in which sulfur dioxide has been oxidized to other compounds, many of which are now more toxic than before the chemical reaction. A combination of ozone and sulfur dioxide in the air is more debilitating than either alone. Weather conditions greatly influence the nature and speed of such chemical changes and their associated health effects on human beings. For example, sulfuric acid mists are more irritating to the respiratory tract when the relative humidity is high.

Sulfur dioxide concentrations of 300 ppb or greater exhibit a pungent odor and can be detected by taste at levels ranging from 300 ppb to 1000 ppb. Excess sulfur oxides cause irritation of the respiratory system with damage being either temporary or permanent. In serious cases damage to the heart can occur. Violation of the primary ambient air quality standards occur when sulfur dioxide concentrations exceed 140 ppb during a 24 hour period or if the annual arithmetic mean exceeds 30 ppb (Figure 3). Secondary standard violations occur when sulfur dioxide levels exceed 500 ppb for non-overlapping three hour averages.

Sulfur dioxide can also cause damage to vegetation when concentrations are as low as 30 ppb. Acute injury to plants occurs when high concentrations of sulfur dioxide are experienced for short periods of time and are manifested in the injured tissue changing to an ivory color. Chronic injury may occur over days or weeks with the result that plant leaves yellow as chlorophyll production is disrupted.

Corrosion rates are usually higher in urban and industrial atmospheres which contain sulfur oxides, as well as particulates, than in rural environments. This type of pollution can damage electrical equipment of all kinds, building materials and textile fibers.

During 1978 none of the monitoring sites in Chicago exceded the primary standard of 30 ppb. The highest annual average value recorded was 18 ppb. There were no violations of either the 24 hour primary or 3 hour secondary average sulfur dioxide standard.

FIGURE 3

SUMMARY OF NATIONAL AND ILLINOIS AMBIENT AIR QUALITY STANDARDS 1978

Pollutant	Time of Average	Primary Standard	Secondary Standard
Particulate Matter (TSP)	Annual Geometric Mean	75 ug/m^3	60 ug/m^3
	24 Hours	260 ug/m^3	150 ug/m^3
Suflur Dioxide (SO_2)	Annual Arithmetic Mean	30 ppb	None
	24 Hours	140 ppb	None
	3 Hours	None	500 ppb
Carbon Monoxide (CO)	8 Hours	9 ppm	Same as Primary
	1 Hour	35 ppm	Same as Primary
Photo-Chemical Oxidants (O_3)	1 Hour (State)	80 ppb	Same as Primary
	1 Hour/day (Federal)	120 ppb	Same as Primary
Non-Methane Hydrocarbons (N-MHC)	3 Hours (6 to 9 AM)	240 ppb	Same as Primary
Nitrogen Dioxide (NO_2)	Annual Arithmetic Mean	50 ppb	Same as Primary

Illinois Air Quality Standards are identical to National Air Quality Standards with the exception of ozone. All standards with averaging time of 24 hours or less are not to be exceeded more than once per year.

Total Suspended Particulates:

Suspended particulates consist of liquid droplets and small solid material dispersed in the atmosphere as mists, sprays, dust, smoke or fumes. Particulates cannot remain suspended in the air unless their diameter is less than 100 microns (diameter of a human hair).

The chemical and physical characteristics of particulates depend on the source of emissions. Some of the most common sources include soot and ash from the combustion of fossil fuels, industrial processes, dust from wind erosion and particles produced from the interaction of sunlight and gaseous pollutants. Suspended particulates derived from combustion and photochemical processes are usually less than one micron in size, whereas dust and industrial derived materials are larger than one micron in size. A major problem occurs when particles in the atmosphere interact with sunlight and moisture to increase local cloudiness and reduce visibility. These conditions can be hazardous for the operation of motor vehicles and aircraft.

Suspended particulates enter the human body through the respiratory system. The size of the particles determines the degree of penetration into the respiratory tract. Particles over five microns are usually trapped and deposited mainly in the nose and throat. Smaller particles, especially one micron or less in diameter, may penetrate deeper into the respiratory system and may eventually be absorbed into the bloodstream. Unfortunately, those particles smaller than one micron are the most difficult to remove from the work environment. Once these particles reach the outside atmosphere they can be washed out rather effectively by rain water. Breathing air which contains high particulate concentrations (annual geometric mean of 80 micrograms per cubic meter or more) have been associated with increased mortality and bronchitis.

Over long periods of time the chemical nature of the deposited particulates may be linked to increased chances of developing lung cancer or having a heart attack.

Within the city of Chicago 38 percent of the monitoring sites exceeded the primary annual standard of 75 micrograms per cubic meter during 1978 (Figure 3). Seven sites recorded violations of the 24 hour primary standard of 260 micrograms per cubic meter.

Carbon Monoxide:

The major source of carbon monoxide emissions is from the incomplete burning of gases generated by the internal combustion engine. Nearly 80 percent of this air pollutant is derived from highway motor vehicles. Secondary sources of carbon monoxide include industrial processes, solid waste disposal, open burning and forest fires.

Carbon monoxide is an invisible, odorless and tasteless gas. The effects of high concentrations of this gas are well known. Carbon monoxide is absorbed into the lungs and reacts with the hemoglobin of the blood. This situation reduces the oxygen carrying capacity of the blood. The level of carbon monoxide that eventually mixes with the blood is directly related to the carbon monoxide concentration of the inhaled air. Once the carbon monoxide concentration is removed or reduced low level poisoning associated with its inhalation can be reversed.

An exposure of eight or more hours to carbon monoxide concentrations of 10 to 15 parts per million (ppm) can impair mental functions. Levels greater than 30 ppm can cause discomfort for persons with heart disease. Studies[4] do not indicate that carbon monoxide has any adverse effects on vegetation, materials, or visibility.

During 1978 the eight hour primary standard of 9 ppm was exceeded 84 times at the State Office Building in downtown Chicago primarily because of heavy traffic congestion. The highest carbon monoxide value recorded at this site during the year was 16.8 ppm. It is not unusual for concentrations of 50 ppm to occur in dense traffic areas in some urban centers, yet 200 yards away the carbon monoxide value may be near zero. No excursions of the one hour primary standard of 35 ppm were recorded (Figure 3). The highest one hour average was 26.4 ppm experienced at the State Office Building site in Chicago.

Nitrogen Dioxide:

When coal, oil and gas are burned at high temperatures in the presence of oxygen atmospheric nitrogen may combine with oxygen to form various nitrogen oxides (NO_x). Stationary fuel combustion and highway vehicles are the two most important sources of such oxides. Nitric oxide (NO) is the primary nitrogen oxide resulting from the combustion process. It is a colorless and odorless gas. Nitric oxide can cause haze and reduce visibility. It can also damage fabrics, electrical equipment and plants may suffer leaf damage and reduced crop yields depending on the concentration of nitric oxide and the time of exposure. Nitric oxide is not known to be harmful to humans at levels found in the atmosphere. Many times, however, nitric oxide is oxidized to nitrogen dioxide (NO_2) which can cause inflammation of the lungs and bronchitis when 24 hour mean concentrations exceed 60 ppb.

Nitrogen oxides ($NO + NO_2$) frequently react in the presence of sunlight and hydrocarbons to produce photochemical oxidants, including ozone. High levels of nitrogen oxides in the morning frequently are related to ozone problems in the afternoon. These very unstable compounds can damage plants and irritate both the eyes and respiratory system of people.

A significant increase in nitrogen dioxide concentrations was evident in the Chicago area during 1978. A total of four sites in Chicago were in violation of the annual primary standard of 50 ppb (Figure 3). The highest one hour average value was 255 ppb recorded at the State Office Building in downtown Chicago. A one square mile area around this site consistently records nitrogen dioxide concentrations which exceed state health standards.

Classroom Exercises

The classroom exercises will ultimately examine the relationship between all five air pollutants and selected weather variables. The detailed discussion of ozone pollution in the classroom provides by example procedures that students can utilize in their investigation of sulfur dioxide, total suspended particulates, carbon monoxide and nitrogen dioxide outside of class. Figure 4 depicts the average monthly and maximum ozone concentrations during 1978 for two sites in the vicinity of Midway Airport(Figure 1). This information was plotted on graphs(Figures 5 and 6) for easier interpretation. It was now possible to quickly determine which months were associated with greater than average ozone concentrations. The yearly average value was exceeded on both graphs during the warmer part of the year, from approximately April to September. The maximum ozone values were not only much higher than mean monthly values but also more variable.

Students would be required to provide reasons for the seasonal variations of both mean and maximum values. What weather variable seems to be most closely associated with high ozone concentrations during the summer? Do mean and maximum ozone values vary directly or indirectly during the year? Why are the mean and maximum values for Kenwood H. S. higher but also more erratic than those recorded at Bedford Park? What possible role do such non-weather factors as distance from Lake Michigan, highway concentration and orientation, distance from Midway Airport and the location of industry have in explaining the variation in concentration of ozone between these two sites? Which factors seem to be most important? What other factors could also be considered in explaining variations in ozone patterns? Answering these questions

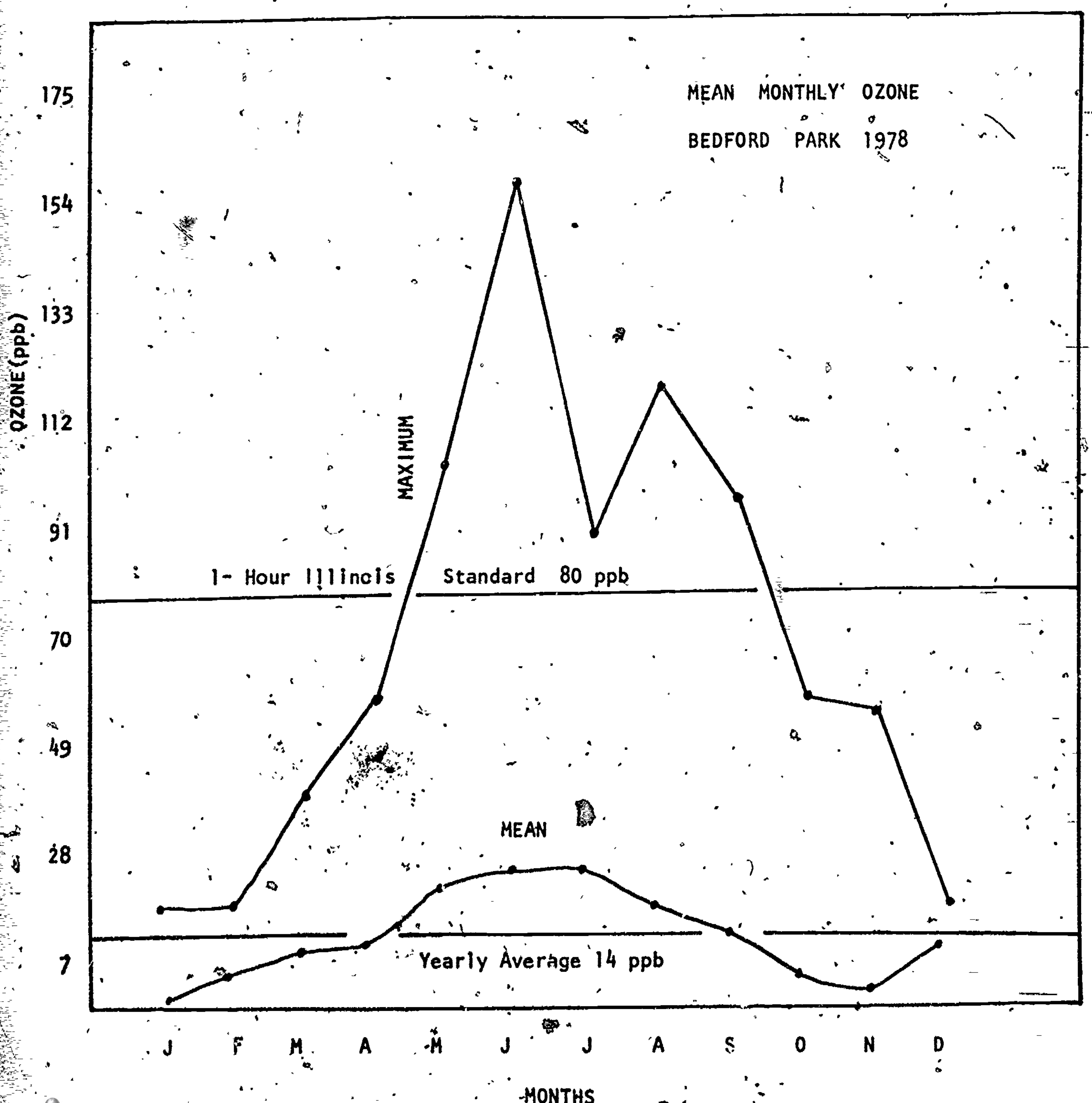
FIGURE 4

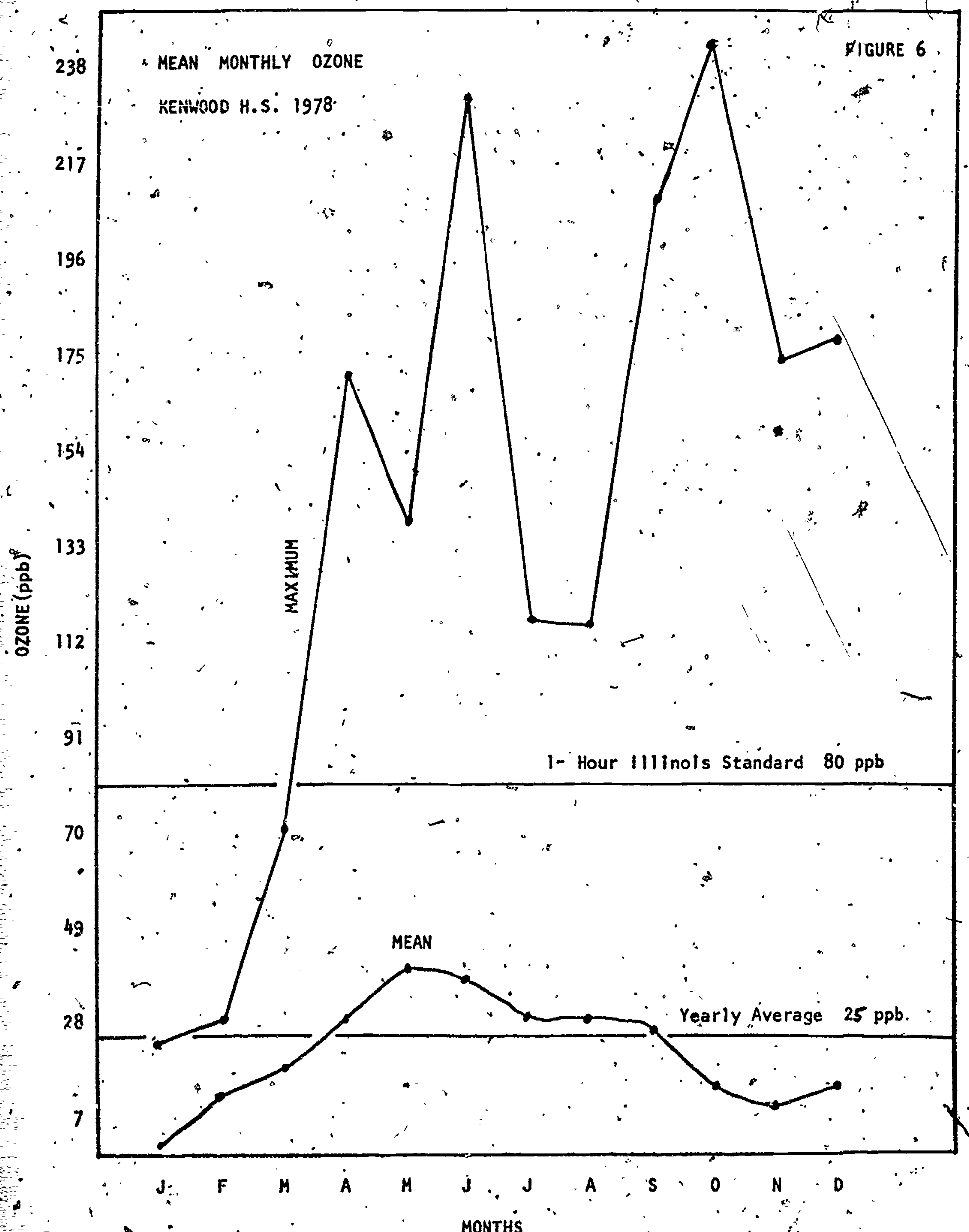
MEAN MONTHLY OZONE VALUES (ppb)
Chicago 1978

Monitoring Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Bedford Park													
Mean	1	6	11	12	23	27	27	20	16	6	3	12	14
Maximum	20	20	40	60	110	160	90	120	100	60	60	20	160
Kenwood H. S.													
Mean	.5	13	19	30	43	39	30	33	29	15	11	16	25
Maximum	24	30	74	175	141	234	120	117	211	247	175	180	247

16

FIGURE 5


MEAN MONTHLY OZONE
BEDFORD PARK 1978
OZONE (ppb)
175
154
133
112
91
70
49
28
7
MAXIMUM
1- Hour Illinois Standard 80 ppb
MEAN
Yearly Average 14 ppb
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS


MEAN MONTHLY OZONE
KENWOOD H.S. 1978
FIGURE 6
238
217
196
175
154
133
112
91
70
49
28
7
OZONE (ppb)
MAXIMUM
1- Hour Illinois Standard 80 ppb
MEAN
Yearly Average 25 ppb.
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS

will require the use of background information discussed earlier in the section on air quality, as well as the use of a road map and/or topographic map of the Chicago metropolitan area. A map of Chicago is found on the back of the Illinois Highway map.

Figure 7 lists the monthly averages for the six weather variables chosen for this study. When plotted on graphs this information could be compared to the graphs of ozone. Do certain weather variables correlate better than others with ozone? For instance, since ozone is highest during the warmer portion of the year it should exhibit a positive correlation with average monthly temperature.

Comparisons using graphs are not very specific but do enable students to quickly make a qualitative assessment of the general relationship between a weather variable and a specific air pollutant. One way to improve on this descriptive approach is to use rank correlation for a more rigorous evaluation of the role that weather plays in aggravating or reducing air pollution. The weather data in Figure 8 have been ranked by using the actual data in Figure 7 and assigning a value of one to the largest value for each weather variable and a value of 12 to the smallest value. Where two or more values of a variable are equal (tied) they are given the same rank by summing and dividing by the number of tied values. This has occurred in three of the six columns in Figure 8 where some values are no longer whole numbers.

Figure 9 reveals the calculations necessary to obtain the Spearman rank correlation (R_S) for the relationship between average monthly ozone concentrations and average temperatures at Bedford Park. The result was a rather high positive correlation coefficient of .79. This means that when temperatures increase so do ozone concentrations, and vice versa. This fact may have been evident

FIGURE 7

WEATHER CONDITIONS AT MIDWAY AIRPORT
MONTHLY AVERAGES 1978

Month	Average Temperature (F)	Total Heating/Cooling Degree Days (F)	Average Station Pressure (in.)	Resultant Wind Direction (Azimuth from N)	Average Wind Speed (mph)	Percentage Sunshine for Month
Jan.	15.9	1517	29.45	280	11.8	43
Feb.	16.8	1346	29.51	280	8.7	43
March	32.4	1003	29.40	330	11.3	44
April	47.9	508	29.32	020	11.5	58
May	58.9	362	29.27	060	10.9	58
June	69.0	196	29.34	190	9.6	63
July	72.7	253	29.32	140	9.0	57
Aug.	73.4	270	29.39	180	7.5	65
Sept.	70.2	263	29.38	200	8.6	69
Oct.	51.6	410	29.40	230	10.0	52
Nov.	42.4	672	29.46	240	10.4	42
Dec.	26.1	1199	29.35	240	11.6	36

20

FIGURE 8

RANKED WEATHER DATA FOR MIDWAY AIRPORT-1978

Month	Average Temperature (F)	Total Heating/Cooling Degree Days (F)	Average Station Pressure (in.)	Resultant Wind Direction (Azimuth from N)	Average Wind Speed (mph)	Percentage Sunshine for Month
Jan.	12	1	3	2.5	1	9.5
Feb.	11	2	1	2.5	10	9.5
March	9	4	4.5	1	4	8
April	7	6	10.5	12	3	4.5
May	5	8	12	11	5	4.5
June	4	12	9	8	8	3
July	2	11	10.5	10	9	6
Aug.	1	9	6	9	12	2
Sept.	3	10	7	7	11	1
Oct.	6	7	4.5	6	7	7
Nov.	8	5	2	4.5	6	11
Dec.	10	3	8	4.5	2	12

Note: highest rank is assigned a value of one.

FIGURE 9

SPEARMAN RANK CORRELATION BETWEEN OZONE AND TEMPERATURE, (Bedford Park 1978)

Month	Ozone Rank	Average Temperature Rank	Difference in Ranks	Differences Squared
Jan.	12	12	0	0
Feb.	9.5	11	-1.5	2.25
March	8	9	-1	1
April	6.5	7	-0.5	.25
May	3	5	-2	4
June	1.5	4	-2.5	6.25
July	1.5	2	-0.5	.25
Aug.	4	1	3	9
Sept.	5	3	2	4
Oct.	9.5	6	3.5	12.25
Nov.	11	8	3	9
Dec	6.5	10	-3.5	12.25

$\Sigma D^2 = 60.5$

Spearman Rank Correlation (R_s): $R_s = 1 - \frac{6 \Sigma D^2}{N(N^2-1)}$

$$R_s = 1 - \frac{6 \times 60.5}{1716} = +.79$$

earlier from the graphic comparison but now has been more clearly established. This technique has the advantage that data does not need to be normally distributed but the disadvantage that mathematical equations for forecasting one variable when the other is known are not available from this type of correlation.

The results of the Spearman rank correlations for all the air pollutants and all the weather variables at the five monitoring sites are listed in Figures 10 and 11. Students would be required to calculate approximately one-half of the values in these tables. Only those values which are significant at the .01 level in Figures 10 and 11 would be discussed and evaluated in class. In this instance only values greater than .71 or less than -.71 are significant at the .01 level. This means that there is only a one percent possibility that the relationship could have occurred by chance. Students would be required to provide reasons why certain air pollutants were strongly correlated with certain weather variables. This exercise would require that they employ sound meteorological principles in explaining each situation. For example, in Figure 11 the rank correlation between average wind speed and nitrogen dioxide concentration at Summit is -.81. This likely means that when wind speeds are high, nitrogen dioxide concentrations are low because high winds disperse the pollutant more effectively than low wind speeds. Monitoring sites in Figures 10 and 11 which are associated with significant correlations would also be compared in an effort to better understand spatial differences among sites in the Chicago area.

The equation to calculate the product moment correlation coefficient(R) is found in Figure 12. Also included is the equation to determine significance according to the student-t test. This correlation coefficient is a better

FIGURE 10

SPEARMAN RANK CORRELATIONS BASED ON AVERAGE MONTHLY VALUES 1978

Weather Variable	Bedford Park (TSP)	Hale Elem. School (TSP)	Summit (TSP)	Bedford Park (SO_2)	Hale Elem. School (SO_2)	Summit (SO_2)
Average Temperature (F)	.65	-.04	.69	-.15	-.58	-.61
Total Heating/ Cooling Degree Days	-.76	-.36	-.73	.28	.56	.73
Average Atmospheric Pressure (in.)	-.42	-.07	-.36	.32	.61	.73
Resultant Wind Direction (degrees)	-.34	-.20	-.46	.41	.75	.75
Average Wind Speed (mph)	-.48	-.09	-.50	.36	.22	.20
Percentage Possible Sunshine	.52	.40	.66	-.35	-.65	-.73

All values greater than .71 or less than -.71 are significant at the .01 level

FIGURE 11

SPEARMAN RANK CORRELATIONS BASED ON AVERAGE MONTHLY VALUES 1978

Weather Variable	Bedford Park (O_3)	Kenwood H.S. (O_3)	Kenwood H.S. (CO)	State Office (CO)	Hale Elem. School (NO_2)	Summit (NO_2)
Average Temperature (F)	.79	.63	.15	.81	.56	.83
Total Heating/ Cooling Degree Days	-.83	-.65	-.31	-.51	-.64	-.76
Average Atmospheric Pressure (in.)	-.80	-.79	-.39	-.67	-.07	-.18
Resultant Wind Direction (degrees)	-.69	-.73	-.22	-.74	.01	-.47
Average Wind Speed (mph)	-.41	-.15	.03	-.44	-.54	-.81
Percentage Possible Sunshine	.68	.80	-.05	.63	.39	.54

All values greater than .71 or less than -.71 are significant at the .01 level

FIGURE 12

PRODUCT MOMENT CORRELATION COEFFICIENT(R)

$$R = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{N}}{\sqrt{\Sigma X^2 - \frac{(\Sigma X)^2}{N}} \cdot \sqrt{\Sigma Y^2 - \frac{(\Sigma Y)^2}{N}}}$$

SIGNIFICANCE TEST USING STUDENT T:

$$t = \frac{R\sqrt{N - 2}}{\sqrt{1 - R^2}}$$

32

measure than the Spearman rank correlation of the strength of a relationship between two variables. It has, however, several restrictions. First, it is a parametric statistic which means that the distribution of the population must be normal, and second it is more time consuming to calculate.

The figures necessary to calculate R for monthly values are displayed in Figure 13 for the Bedford Park monitoring site. The summed values would be used in the first equation in Figure 12 to calculate the correlation coefficient. This example would be utilized by students to complete Figures 14 and 15. Only those values which are significant at the .01 level in Figures 10 and 11 would be used to calculate this new value. The total number of computations required to complete Figures 14 and 15 was only 25% of that required for Figures 10 and 11.

The values displayed in Figures 14 and 15 which are greater than .68 or less than -.68 are significant at the .01 level. If time permits students can be instructed in how to actually determine the level of significance and the associated correlation coefficient. The second equation in Figure 12 would be required to make such calculations, as well as a table of student-t values. After the tables are completed students would again be required to provide reasons why certain relationships existed between a given air pollutant and a weather variable. The questions to be considered are similar to those listed earlier in the discussion of the graphs of ozone concentration.

Finally, an example of daily ozone values for Bedford Park for the month of June 1978 is displayed in Figure 16. In this case, a product moment correlation coefficient is computed for daily average ozone values and average temperatures. The example in Figure 15 was computed in the same fashion as the example in Figure 13 except that more cases were involved. The monthly

FIGURE 13

PRODUCT MOMENT CORRELATION COEFFICIENT (R)
Bedford Park 1978

Months	Ozone (X) (ppb)	Average Temperature (F) (Y)	X^2	Y^2	XY
Jan.	1	15.9	1	253	15.9
Feb.	6	16.8	36	282	101
March	11	32.4	121	1050	356
April	12	47.9	144	2294	575
May	23	58.9	529	3469	1355
June	27	69.0	729	4761	1863
July	27	72.7	729	5285	1963
Aug.	20	73.4	400	5388	1468
Sept.	16	70.2	256	4928	1123
Oct.	6	51.6	36	2663	310
Nov.	3	42.4	9	1798	127
Dec.	12	26.1	144	681	313
	$\Sigma X=164$	$\Sigma Y=577$	$\Sigma X^2=3134$	$\Sigma Y^2=32852$	$\Sigma XY=9570$

Some of the above values have been rounded

FIGURE 14

PRODUCT MOMENT CORRELATION COEFFICIENT (R)
Monthly Average Values
1978

Weather Variable	Bedford Park (TSP)	Hale Elem. School (TSP)	Summit (TSP)	Bedford Park (SO_2)	Hale Elem. School (SO_2)	Summit (SO_2)
Average Temperature (F)	-	-	-	-	-	-
Total Heating/ Cooling Degree Days	-.66	-	-.73	-	-	.63
Average Atmospheric Pressure (in.)	-	-	-	-	-	.12
Resultant Wind Direction (degrees)	-	-	-	-	.62	.50
Average Wind Speed (mph)	-	-	-	-	-	-
Percentage Possible Sunshine	-	-	-	-	-	-.78

All values greater than .68 or less than -.68 are significant at the .01 level

FIGURE 15

PRODUCT MOMENT CORRELATION COEFFICIENT (R)
Monthly Average Values
1978

Weather Variable	Bedford Park (O_3)	Kenwood H.S. (O_3)	Kenwood H.S. CO)	State Office Bldg. (CO)	Hale Elem. School (NO_2)	Summit (NO_2)
Average Temperature (F)	.79	-	-	.84	-	.80
Total Heating/ Cooling Degree Days	-.72	-	-	-	-	-.73
Average Atmospheric Pressure (in.)	-.17	-.20	-	-	-	-
Resultant Wind Direction (degrees)	-	-.68	-	-.77	-	-
Average Wind Speed (mph)	-	-	-	-	-	-.87
Percentage Possible Sunshine	-	.76	-	-	-	-

All values greater than .68 or less than -.68 are significant at the .01 level.

FIGURE 16

PRODUCT MOMENT CORRELATION COEFFICIENT(R)
Daily Values for Bedford Park--June 1978

Ozone (X) (ppb)	Average Temperature (F) (Y)	X^2	Y^2	XY
22	76	484	5776	1672
18	64	324	4096	1152
25	61	625	3721	1525
22	65	484	4225	1430
18	60	324	3600	1080
31	71	961	5041	2201
23	67	529	4489	1541
12	54	144	2916	648
20	63	400	3969	1260
33	68	1089	4624	2244
48	77	2304	5929	3696
19	64	361	4096	1216
14	56	196	3136	784
12	62	144	3844	744
30	70	900	4900	2100
25	74	625	5476	1850
49	78	2401	6084	3822
25	72	625	5184	1800
37	70	1369	4900	2590
23	75	529	5625	1725
21	66	441	4356	1386
33	66	1089	4356	2178
21	67	441	4489	1407
50	74	2500	5476	3700
16	71	256	5041	1136
25	76	625	5776	1900
29	77	841	5929	2233
38	76	1444	5776	2888
50	77	2500	5929	3850
19	77	361	5929	1463
$\Sigma X=808$	$\Sigma Y=2074$	$\Sigma X^2=25316$	$\Sigma Y^2=$ 144688	$\Sigma XY=$ 57221

R values for these two variables in Figure 15 was .79. Again only 11 of 18 values which were significant in Figures 14 and 15 would have R values calculated for the monthly data which comprised Figure 17. The results in this table indicate that only one of the 11 values is significant at the .01 level and only two are significant at the .05 level(R equals .38 or greater). The reduction in the value of R_s and R provides an opportunity to explore more carefully the effect that the two different correlation procedures, as well as time intervals have on the results. Students will have to reevaluate and revise explanations which were employed early in the study in order to ultimately arrive at some general conclusions about the relationship of air pollution and the weather.

Future Work

Additional investigations of weather and air quality relationships would involve the use of the computer. Both the interative terminal and batch mode would be utilized to expand the initial study. Multivariate techniques such as principal components analysis and stepwise multiple regression would be employed to better understand how air pollution concentrations are affected by not just one weather variable but simultaneously by several such variables. In this instance, the dependent variable would be the concentration of an air pollutant and the independent variables would be the six weather variables listed in Figure 7. The time frame for such examinations would include monthly and daily, as well as seasonal, day of the week and hourly intervals. Students would again have the opportunity to examine in greater detail, and even begin to develop hypotheses, about the role that weather plays in affecting air pollution concentrations.

FIGURE 17

PRODUCT MOMENT CORRELATION COEFFICIENT (R)
Daily Average Values

Weather Variable	Summit (TSP)	Summit (SO_2)	Bedford Park (O_3)	Kenwood H.S. (O_3)	State Office Bldg. (CO)	Summit (NO_2)
Average Temperature (F)	-	-	.63	-	.24	.25
Total Heating/ Cooling Degree Days	-.07	-	.38	-	-	.26
Average Atmospheric Pressure (in.)	-	-	-	-	-	-
Resultant Wind Direction (degrees)	-	-	-	-.06	.10	-
Average Wind Speed (mph)	-	-	-	-	-	-.25
Percentage Possible Sunshine	-	.15	-	.12	-	-

*All values greater than .46 or less than -.46 are significant at the .01 level.

FOOTNOTES

1. Illinois Environmental Protection Agency. Illinois Environmental Progress, Volume III, No. 7(Nov./Dec., 1978), p. 6.

2. The assistance of Mr. Terry A. Sweitzer of the Division of Air Pollution Control in acquiring the data is gratefully acknowledged.

3. Twardy, Stan. Ozone Pollution in Illinois. Document No. 77/25 Chicago: Illinois Institute for Environmental Quality, (July 1977), p. 9.

4. Illinois Environmental Protection Agency. Illinois Air Quality Report 1978. Springfield: Division of Air Pollution Control, p. 9-10.

40

REFERENCES

Council on Environmental Quality. The Eleventh Annual Report. Washington, D.C.: U.S. Government Printing Office, December 1980.

Hammond, Robert and Patrick McCullagh. Quantitative Techniques in Geography: An Introduction. Oxford: Clarendon Press, Second Edition, 1978.

Theakstone, W. H. and C. Harrison. The Analysis of Geographical Data. London: Heinemann Educational Books, 1975.